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16. ABSTRACT

Techniques are available to minimize the concentration of asbestos fibers in drinking water. Granular media filtration can remove over 99% of the asbestos fibers found in source waters when the raw water is coagulated properly and effluent turbidity is 0.10 ntu or lower. Asbestos cement pipes can be protected by modifying low pH, low alkalinity waters so they are not aggressive; by coating the pipe wall with a chemical precipitate; or by applying a cement mortar lining to the pipe wall. Modification of distribution system practices related to main flushing and pipe tapping can also reduce the fiber count in tap water.

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Engineering and Operating Approaches for Controlling Asbestos Fibers in Drinking Water

by Gary S. Logsdon*

Techniques are available to minimize the concentration of asbestos fibers in drinking water. Filtration research conducted at locations on Lake Superior and in the Cascade Mountains in Washington has shown that amphibole and chrysotile fibers can be removed by granular media filtration. Removal percentages can exceed 99% when the raw water is coagulated properly and the filtered water turbidity is 0.10 ntu (nephelometric turbidity units) or lower. Filtered water fiber counts below detectable limits of 0.1 to 0.01 × 10^6 fibers/L can be attained. A study by the Metropolitan Water District of Southern California showed that when raw water chrysotile counts ranged from 200 × 10^6 fibers/L to 2000 × 10^6 fibers/L, filtered water fiber counts frequently exceeded 1 × 10^6 fibers/L. Even so, striving to attain a filtered water turbidity of 0.1 ntu resulted in improved fiber removal.

Pilot scale and distribution system research projects have shown that asbestos cement (AC) pipes can be protected from dissolution and leaching effects that can result in release of asbestos fibers into drinking water. Suggested techniques include modifying low pH, low alkalinity waters so they are not aggressive; coating the pipe wall with a chemical precipitate; and applying a cement mortar lining to the pipe wall.

Operation and maintenance practices related to the distribution system, when AC water mains are in service, can influence the fiber count in tapwater. Main flushing can stir up sediment that accumulates in low-flow and dead-end areas, raising the fiber count. If mains are tapped and the cuttings are not flushed away through the tapping machine, but are instead permitted to fall into the water main, the fiber count can be raised.

Introduction

The discovery of asbestos fibers in the drinking water of Duluth, MN, in 1973 caused a high level of interest in the health implications of ingested asbestos. While health effects studies were being planned and carried out, engineering investigations were also undertaken to develop information on effective techniques for removing asbestos fibers from drinking water. At the same time, work was started on evaluation of techniques to control or eliminate the deterioration of asbestos cement (AC) pipe by aggressive waters.

This paper summarizes results of research efforts related to water filtration and to protection or rehabilitation of AC pipe that transmits aggressive water. When asbestos fibers are present in the source water, filtration plants can be designed and operated to remove most of the fibers. When AC pipe is used to transmit aggressive water, formation of a coating on the pipe wall can decrease the extent of deterioration of the pipe and the erosion of fibers from the pipe wall into the water.

Control of Asbestos in Raw Water

Water filtration processes, when operated properly, have been shown to reduce substantially the asbestos fiber concentrations in drinking water. Pilot plant studies in Duluth in 1974 showed that both granular media filtration and diatomaceous earth filtration could produce low turbidity filtered waters with greatly reduced amphibole fiber concentrations (*1*). Treatment of raw water with alum and nonionic polymer was the most effective technique for granular media filtration. Diatomaceous earth (DE) filtration techniques that were most effective involved conditioning the diatomaceous earth filter aid with alum or a

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polymer or conditioning the raw water with a polymer. Pressure DE filtration was more effective than vacuum DE filtration.

Filtration plants on Lake Superior were built or remodeled at Duluth, Two Harbors, Beaver Bay, and Silver Bay in Minnesota. The Lakewood Filtration Plant at Duluth has been studied and reported upon extensively (*2–4*). Filtered water generally contained fewer than 0.10×10^6 fibers/L and had a turbidity below 0.10 ntu (nephelometric turbidity units). Funds for transmission electron microscope (TEM) analysis of water samples from the other treatment plants were considerably more limited, but some data are available on facilities at Silver Bay and Two Harbors (*5*). These plants use alum as the coagulant and nonionic polymer as a coagulant aid or filter aid. Dual media or mixed media filtration is employed. Plants at Silver Bay and Two Harbors have been able to attain amphibole fiber count reductions of 99% and more (*5*).

Pilot plant studies of granular media filtration were conducted in the Cascade Mountains in 1977–1978. Extensive research was conducted at Seattle's South Fork Tolt Reservoir (*6, 7*). A limited amount of research on asbestos fiber removal was also carried out as a part of a pilot plant study at Everett, Washington (*8*). Chrysotile fiber removal exceeding 99% was demonstrated in both of these projects.

After the Lake Superior and Cascade Mountain studies were completed, pilot plant and full-scale treatment plant operating data were reviewed and summarized (*5*). The relationship between filtered water turbidity and fiber count was scrutinized in a paper by Logsdon et al. (*9*), who concluded that granular media filters should be operated to produce a turbidity of 0.10 ntu or lower if fiber removal is a goal of filter operation. The most important factor involved is properly conditioning the raw water before filtration so that a very low effluent turbidity is produced. Alum and cationic polymers have usually been used for coagulation. Nonionic polymers often are used as filter aids. Control of coagulant dose, to assure thorough and complete particle charge destabilization, is essential, as is careful control of process pH. Filter rates from 2 to 10 gal/min/ft^2 (5 to 24 m/hr) have removed asbestos fibers, but abrupt rate changes must be avoided, particularly if floc is not strong and could pass through the filter as a result of a rate increase. A turbidity of 0.10 ntu was suggested as an appropriate goal for filtered water. Asbestos fiber counts are likely to increase very substantially as filtered water turbidity rises, so increases in turbidity over 0.10 ntu should be interpreted as a signal for corrective action by filter plant operators. Because turbidity is only an indicator of the presence of particulates in water, attaining the lowest possible filtered water turbidity would be the best way to assure that a filtration plant is operating at maximum effectiveness.

A more recent report by McGuire et al. (*10*) questioned whether using 0.10 ntu as a surrogate level for asbestos fibers would be adequate. They reported that filtered water chrysotile concentrations were frequently in the range of 1×10^6 fibers/L to 50×10^6 fibers/L at three treatment plants of the Metropolitan Water District of Southern California (MWDSC), where raw water fiber counts generally ranged from 200×10^6 to 2000×10^6 fibers/L. This was observed even when filtered water turbidity in the plant effluent was near or below 0.10 ntu.

The MWDSC study at the treatment plants was divided into two recurring intervals of operation. During standard plant operation, turbidities normally were in the range of 0.20 ntu to 0.35 ntu. In the periods of optimized operation, extra treatment chemicals were used to lower the filtered water turbidity to 0.10 ntu or below as frequently as possible. Probability plots (*10*) showed that

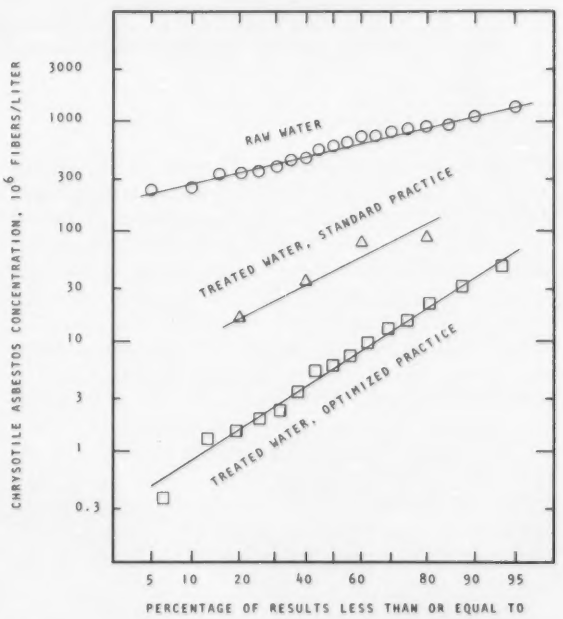

FIGURE 1. Asbestos concentrations in raw and treated water at Weymouth Filtration Plant (data from Metropolitan Water District of Southern California).

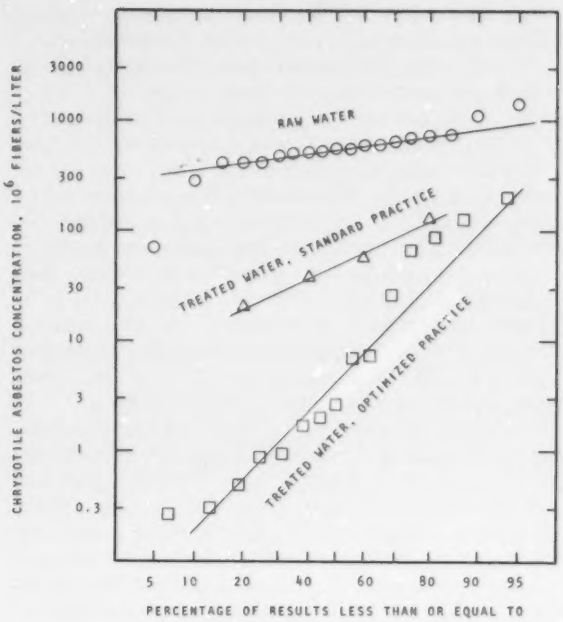

FIGURE 2. Asbestos concentrations in raw and treated water at Diemer Filtration Plant (data from Metropolitan Water District of Southern California).

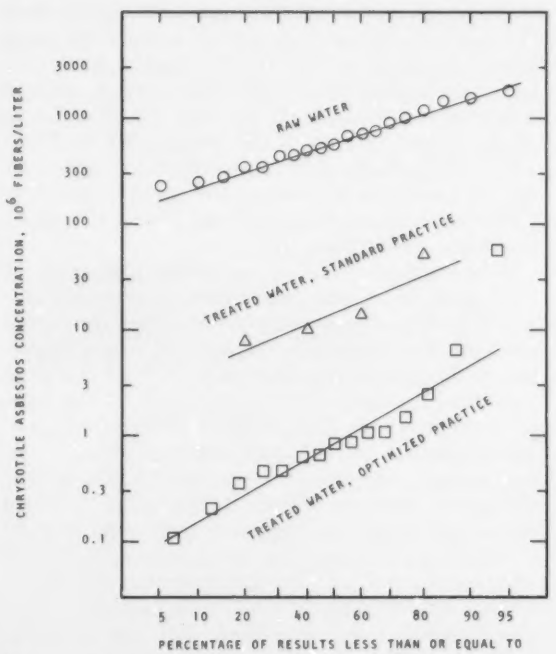

FIGURE 3. Asbestos concentrations in raw and treated water at Mills Filtration Plant (data from Metropolitan Water District of Southern California).

optimized turbidity values were lower, but the comparison of optimized to standard operation was somewhat different for each plant. For the three plants with the highest raw water asbestos concentrations and no filtered water samples with below detectable limit (BDL) values (Weymouth, Diemer, and Mills plants), log-probability plots of filtered water asbestos counts for standardized versus optimized operation are shown in Figures 1–3. The trends of the optimized count data are different for each plant, but for every plant the median value for the optimized operation is considerably below the median for the standardized operation. Even though the fiber counts are not usually below 1×10^6 fibers/L or at BDL values, lower fiber counts unquestionably are a result of the optimized operation.

Two important factors may have led to the different conclusions about the value of the 0.10 ntu goal in the Great Lakes—Cascade Mountain studies versus the MWDSC study. First, the concentration of fibers in the raw water source in California was much higher on a continuing basis. Typical raw water amphibole counts at Duluth were 10×10^6 to 200×10^6 fibers/L (*5*), about one-tenth of the California values. In the Seattle Tolt Reservoir study, about four-fifths of the raw water chrysotile counts were in the 2×10^6 to 10×10^6 fibers/L range (*6*). Attaining nearly complete removal of fibers, as indicated by values below the detection limit (BDL), was easier when the raw water fiber count was lower.

A second and important difference is that whereas earlier work focused on the turbidity and fiber concentration of individual filters, in the MWDSC study the treatment plant influent and effluent waters were sampled. This resulted in sampling the average water quality of numerous filters. This distinction is very important because turbidity and fiber count do not have a linear relationship. Fiber counts can increase dramatically with modest increases in turbidity. Data from the Seattle study (*6*) are shown in Table 1. The effect of a turbidity increase in the fiber count can be substantial. For example, at a hypothetical plant with 10 filters producing water with 0.10 ntu and 1.0×10^6 fibers/L, if a turbidity rise in one filter to 0.30 ntu were accompanied by a fiber count increase to 30×10^6 fibers/L, the blended turbidity would average 0.12 ntu, a small increase, but the fiber count would average 3.9×10^6 fibers/L, a large increase. Thus, if all filtered water is piped into a clearwell and the various effluents are blended before turbidity is measured, quality deterioration in a single filter may be overlooked because of the averaging effect of

Table 1. Chrysotile counts associated with turbidity changes in Seattle Tolt Pilot Plant Study.

Run	Hour in run	Turbidity (ntu)	Chrysotile fibers × 10-6, fibers/L[a]
21	6	0.06	0.16 (NSS)
21	7	0.34	12.25
21	8	0.07	0.19
24	6	0.085	0.34
24	7	0.36	6.2
24	13	0.6	0.13
62	3	0.10	0.34
62	9	0.105	0.24
62	16	0.37	2.28
120	12	0.06	0.1 (NSS)
120	13	0.07	<0.01 (BDL)
120	17	0.07	0.02 (NSS)
120	21	0.48	0.28
120	23	1.2	1.25
174 CCM	1	0.070	0.02 (NSS)
174 CCM	1.5	0.21	0.94
174 CMM	2	0.068	<0.01 (BDL)

[a]NSS = not statistically significant; BDL = below detectable limit.

the clearwell. This may have occurred in the MWDSC study.

The differences in raw water quality and sampling technique certainly must be responsible for some of the reported differences in results of various studies, but other factors probably are involved too. Additional research at treatment plants with very high raw water fiber counts is needed to fully explain the results obtained at MWDSC and the apparent shortcomings of the 0.10 ntu quality goal. The Seattle study showed, and the MWDSC indirectly confirmed, that use of a continuous turbidimeter at each filter is needed to enable plant operators to closely monitor and control filtration plant operation.

Control of Asbestos from AC Pipes

Asbestos cement (AC) pipe has captured a larger share of the water distribution system market in recent years. The *American City & County* 1981 Water Main Pipe Survey (*11*) found that the proportion of AC pipe in place was 13.9% in 1980, as compared with 10.8% in 1975; for pipe installed in a single year, it was estimated that 30% of pipe installed in 1974 was AC versus 40% in 1980. The popularity of AC pipe probably results in part from its lower cost in smaller diameters. In sizes up to 12 inches, AC pipe can cost up to 50% less per foot than ductile iron (*11*).

In the early 1970s, concerns about asbestos fibers in drinking water led to investigations of the potential for contribution of asbestos fibers from AC pipes used to carry water. In 1974, a special report on this problem was published by the American Water Works Association (*12*). One of the projects described in the report was an AC pipe loop water recirculation study conducted by Johns-Manville. An EPA project to verify the results of the earlier pipe loop study was begun in 1974 (*13*). When the operation of a pipe loop containing 4-in. and 6-in. AC pipes proved to be extremely difficult, a system of 100-gal. recirculating tanks was developed and used by Buelow et al. (*13*). AC pipe coupons (1.5 × 6 in.) were exposed to the test water in these tanks.

During the same time period, evaluations of AC pipes in field use were conducted at 10 locations (*13*). Four systems with soft, low pH water had deteriorated AC pipe. Problems in one system included clogged water meters, fiber accumulation at strainers on washing machine hoses at a laundromat, and fiber buildup in a kitchen faucet strainer. Thus the field investigations established that aggressive water can attack AC pipe and showed the need for studies of ways to prevent the attack on the pipe or to rehabilitate deteriorated pipe.

Laboratory and field studies have shown that the deposition of a coating may protect AC pipe. Iron coatings were reported by Buelow et al. (*13*) to be protective in a water distribution system and in an experimental pipe loop, but use of iron might result in complaints from rusty or "red" water. Deposition of calcium carbonate layers on AC pipe coupons as well as coating AC pipe coupons with a zinc precipitate was shown to impart protection to the pipe (*13*).

A theoretical explanation of the protection of AC pipe by zinc, iron, and calcium carbonate was given by Schock and Buelow (*14*). They concluded that the Aggressiveness Index (*15*) is not appropriate for predicting fiber release from AC pipe and deterioration of the inner wall of the pipe because the index fails to take into account possible protective constituents such as silica, iron, manganese, and zinc and because the pipe wall is primarily calcium silicate rather than calcium carbonate. They also reported that some coating mechanisms may prevent the release of fibers but not seal the cement pipe matrix from dissolution. In regard to the use of zinc compounds for corrosion control, they concluded that the chloride, sulfate and orthophosphate salts of zinc protected AC pipe by formation of zinc hydroxycarbonate precipitate, but that only zinc orthophosphate

also offered protection for metal pipe in systems containing both AC pipe and lead service lines or plumbing (*14*). AC pipe protection by zinc precipitation is pH dependent. Best results are expected at pH values above 8.0.

Field studies have been performed to evaluate AC pipe protection on a larger scale. At Greenwood, SC (*16*), storage tanks and chemical feed pumps were set up at each of the water treatment plants, and zinc orthophosphate was fed into the system at an average rate of 0.3 mg/L. Two sections of new AC pipe, which were removable for testing, were installed to represent a low-flow and a high-flow water condition. Samples were periodically tested to determine the number of asbestos fibers in the water. The two pipe sections were removed and examined for the amount of zinc deposited on the surface.

Although routine tests, such as pH and alkalinity, showed no significant changes during the study period, asbestos fibers in the water decreased substantially. Electron microscope photographs and energy-dispersive X-ray spectra analyses showed coatings of zinc products on the two pipe samples. Thus, adding zinc orthophosphate under the existing water quality conditions reduced or prevented corrosion of AC pipe.

In a project now underway at Bellevue, Washington, corrosion control strategies have been tested in 100-gal. recirculating tanks, similar to the systems designed and used by Buelow. The tanks at Bellevue are made of polyethylene, rather than stainless steel, minimizing the amount of any kind of metal in the system. The Seattle Water Department, which sells water to Bellevue, has begun to implement a corrosion control program for both the Cedar River water and Tolt River water. Because little or no AC pipe is used in the City of Seattle water distribution system, the objective of Seattle's program is to protect the galvanized pipe and copper pipe in water consumers' plumbing. A corrosion control strategy to protect Bellevue's AC pipe might involve attainment of a water quality different from that of Seattle's or the use of other additivies.

The eight experimental tank tests were started in April 1981 and have been completed. The conditions for each tank are given in Table 2. The zinc chloride corrosion control strategies tested in tanks T5 and T6 were most efficacious in controlling the attack of AC pipe by Tolt water. No substantial difference was observed between the pH 8.0, 0.6 mg/L zinc dose tank (T6) and the pH 8.5, 0.3 mg/L zinc dose tank (T5); both appear to work well. This conclusion is based on water quality sampling during the testing program, asbestos fiber counts, and evaluation of the AC coupons exposed to the test waters. Coupon evaluation included hardness tests, weight loss data, and calcium loss measurements made via scanning electron microscope (SEM). During the next phase of the study, addition of about 0.6 mg/L of zinc at pH 8.0 will be evaluated in a portion of Bellevue's distribution system.

Table 2. Bellevue Pipe Protection Study.

Tank	Source	Condition of treatment
1	Tolt	No corrosion control
2	Cedar	No corrosion control
3	Cedar	Seattle strategy; add lime to pH 8.0
4	Cedar	Seattle strategy; plus lime and soda ash, pH 9.0
5	Cedar	Seattle strategy; plus zinc chloride, 0.3 mg/L Zn, pH 8.5
6	Cedar	Seattle strategy; plus zinc chloride, 0.6 mg/L Zn, pH 8.0
7	Cedar	Seattle strategy; plus sodium metasilicate
8	Cedar	Seattle strategy; plus 0.1-0.3 mg/L Fe (ferric chloride)

Buelow observed that some AC pipe coupons used in the recirculating tank studies had softened when exposed to aggressive water and could be gouged by a fingernail, whereas new AC pipe coupons could not be scratched in this manner (*13*). The hardness of AC coupons was tested at Bellevue to learn if the pipe had been attacked by aggressive water. Two techniques, the Rockwell "L" scale test and the Durometer hardness test, have been used. Results were consistent between the two types of test. Leaching of calcium from the AC pipe wall can result in softening of the cement material that bonds the fibers in the pipe. This work is a part of the search for an inexpensive, uncomplicated test to evaluate the condition of the inner pipe wall.

Preliminary hardness testing data indicate reasonable results. Table 3 shows the test data from the testing laboratory. The differences between means were significant at the 0.05 level for both pipe A and pipe B as compared to the new pipe C. These procedures will continue to be used during the course of the study.

Discovery of deteriorated AC pipe in one part of the distribution system of the Town of Weston Water Utility resulted in application for an award of a cooperative agreement for in-place rehabilitation of AC pipe. In 1980, a water main was isolated from the distribution system for the research. Parts of the pipeline were treated by Polly Pigs, bullet-shaped foam swabs forced through the main by hydraulic pressure. Other sections

Table 3. Hardness test results for AC coupons (3/25/81).

	Sample number	Shore D hardness	Rockwell hardness "L" Scale
Pipe	A-1	67	7
exposed to	A-2	65	10
Tolt water	A-3	66	5
	A-4	64	14
Average ± standard deviation		65.5 ± 1.29	9.0 ± 3.92
Used pipe,	B-1	68	64
history	B-2	74	60
unknown	B-3	67	65
	B-4	73	56
Average ± standard deviation		70.5 ± 3.51	61.25 ± 4.11
New pipe	C-1	79	99
	C-2	81	100
	C-3	82	98
	C-4	78	98
Average ± standard deviation		80.0 ± 1.83	98.7 ± 0.96

were cleaned and scraped with metal scrapers that were pulled through the main by the Centriline Department of Raymond International, Inc. In 1981 the entire main (three blocks) was lined with cement mortar.

In this project, Bakelite-mounted specimens of the AC pipe were prepared and studied. The pipe segment was cut and mounted so that the exposed surface of the pipe in the mount had, on one side, the inner pipe wall and, on the other side, the outer pipe wall. This mounting arrangement permitted observation of a cross section of the pipe.

The pipe cross section was studied by an X-ray analysis technique using the scanning electron microscope. Elemental profiles of calcium and silicon concentrations were produced. In new AC pipe, the calcium and silicon concentrations are constant from the pipe inner wall through the pipe to the outer wall. In used pieces of pipe from Weston, however, the silicon concentration was constant, but the calcium concentration was lower near the inner wall when compared to other locations deeper within the pipe wall. The depth of the pipe showing lower calcium concentrations ranged from 2.1 mm to 6.5 mm. Analysis of AC pipe cross sections from four other cities showed calcium losses to depths ranging from 0.8 mm to 3.6 mm. This technique produces a quantitative measure of pipe deterioration.

Results of analysis for asbestos fibers in water circulated in the Weston test mains suggest that although scraping or pigging AC mains can remove the softened portion of the pipe wall, such procedures greatly increase the fiber count of water transmitted in the pipes. Making firm conclusions about the effect of cement mortar lining as a barrier to passage of asbestos fibers from AC pipe into drinking water is not possible because of the poor precision of the asbestos counting procedure when fiber concentrations are low. Nevertheless, a mortar lining would be expected to be a positive barrier to passage of fibers from the pipe wall into drinking water.

Support for the efficacy of the mortar lining as a barrier to asbestos fibers comes from another mortar lining project. Test sections of vinyl-lined AC pipes were lined with cement mortar in the Town of Ashland, Massachusetts, in order to reduce or prevent the leaching of 1,1,2,2-tetrachloroethylene (TCE) into drinking water (*17*). Two mortar-lined sections of AC pipe were compared for a 2-month period with two control sections of vinyl-lined AC pipe. In the test section from which the vinyl liner was removed before the mortar lining was applied, TCE concentrations in the static test water were reduced by 96.2–99.5% as compared to the controls. TCE reductions ranging from 98.2–99.4% were observed in the test pipe in which the cement mortar lining had been placed directly over the vinyl liner. TCE concentrations in the mortar-lined pipes ranged from 25 to 1169 μg/L, while concentrations in the control pipes ranged from 2800 to 74,800 μg/L. Because of the precision with which TCE can be measured in water, much greater confidence can be placed in the Ashland, Massachusetts, TCE data than in the Weston, WI, asbestos data. The Ashland results indicate that because a cement mortar lining can greatly reduce leaching of organic molecules into water, the lining should be a positive barrier to the passage of fibers into water from AC pipe.

Distribution system operation and maintenance procedures can have a substantial impact on the fiber count of drinking water transmitted by AC pipe. According to Buelow et al. (*13*), when AC pipe under pressure is drilled and tapped, if the cuttings are not flushed out through the tapping machine, they can drop into the pipe and cause a major release of fibers. This problem can be avoided by using tapping machines equipped with flushing devices.

High water flows in the distribution system can also cause high fiber counts. High flows caused by flushing or firefighting can stir up sediment in AC mains. If this happens in low-flow areas, fiber counts can rise to 10 or even 100 times the typical values found when flow conditions are normal. In

one Wisconsin system (*18*), flushing an AC water main for 1 min resulted in a concentration of about 10 billion fibers/L in a sample from a fire hydrant. Fiber concentrations in undisturbed household tap samples were about 5–7 million fibers/L. Main flushing, when it is done, should be carried out for a long enough time to thoroughly remove debris from water mains. This has been investigated at Weston, but further study may be needed before definitive recommendations can be made.

Summary

Water filtration for asbestos fiber removal has been studied extensively in Duluth, MN, and in other Minnesota communities located on Lake Superior; in the Cascade Mountains in Washington; and in southern California. Diatomaceous earth filters and granular media filters have been shown to be capable of removing asbestos fibers from source waters.

Corrosion control techniques and water distribution system conditions have been evaluated to show what approaches might be taken to prevent the deterioration of AC pipe carrying aggressive water. Studies have been done at the Drinking Water Research Division's laboratory in Cincinnati, in South Carolina, in Washington, and elsewhere. Each project focused on the effects of various kinds of coatings that may form on pipe walls. A Wisconsin study was also conducted to evaluate what may be the most durable of all coatings, a cement mortar lining.

Water distribution system research revealed that utility operating practices can influence asbestos fiber concentration in drinking water. Drilling and tapping can introduce asbestos-containing debris into the distribution system unless pipe fragments are flushed out under pressure during the tapping process. After asbestos-containing debris has accumulated in the low-flow or dead-end areas of distribution systems, flushing such water mains can cause unusually high fiber counts.

Although the health effects issues are not completely resolved, EPA has recommended that asbestos exposure be minimized when possible (*19*). The techniques used to minimize asbestos exposure may also bring about other water quality improvements. More effective water filtration has greater potential for removal of viruses, Giardia cysts, and bacteria as well as fibers. An active corrosion control effort may help to prevent other corrosion problems in metal pipes. Better distribution system operation and maintenance practices will decrease the amount of debris passing to the taps of water consumers. Attaining these improvements would be consistent with good water works practice.

The research described in this paper has been peer and administratively reviewed by the U.S. Environmental Protection Agency and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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